side rainfall was almost everywhere moderate, although a few slides were reported from the C. R. Railroad in the valley of Reventazon.

Notes on earthquakes.—October 5, 2^h 13^m a. m., slight shock NE–SE., intensity II, duration 13 seconds. Also reported from Tres Rios.

A STUDY OF THE SUMMER FOGS OF BUZZARDS BAY.

By Mr. FRANK W. PROCTOR, dated Fairhaven, Mass., October 25, 1903.

Fog is moderately frequent in summer over Buzzards Bay on the south coast of Massachusetts. It occurs irregularly, without apparent system, and lasts for periods varying from a few hours to several days. There are no obvious weather changes immediately preceding the visitations of these fogs which might suggest their cause. The irregularity of their occurrence and duration make them an interesting study.

North of Cape Cod, in Massachusetts Bay, the water of the ocean quite to the shore is notoriously chilly; the fogs are popularly attributed to the cooling of moist air from the Gulf Stream by the Labrador current along the coast. But on the southern shore of Massachusetts the water is so much warmer that ocean bathing is comfortable in summer and there is little to suggest an arctic current.

Radiation, or ground fog, is rare here at this season, and breezes from the land are seldom cool enough to condense the vapor rising from the warm surface water of the bay. The fogs that commonly occur here in July, August, and September usually come with southwesterly winds, which are the prevailing winds of summer. These winds blow daily with much regularity, augmented by the sea breeze, and interrupted only by occasional errant highs and lows. But only a small percentage of these southwesterly winds, coming in cool from the ocean, are attended with fog, though the high temperature of the shallow waters of the bay and sounds, and the large vapor content of the lower air would seem to constitute conditions favorable to local condensation.

Every one knows that fog is condensed aqueous vapor. The requisite degree of saturation may be caused either by an increase of vapor pressure, or by a reduction of the temperature or by both in combination. In the absence of observations with thermometer and hygrometer it is impossible to know in what proportions these two factors contribute to produce a fog.

To fully understand the phenomenon of fog formation it is necessary to know the cause of the reduction of the temperature, and the source of the vapor increment. Since the cooling may come from radiation, conduction, adiabatic expansion, or mixture with cold air from elsewhere, and the added vapor may come from local evaporation or from moist air currents, it is not always a simple matter to determine how a fog has been formed. The problem becomes still more difficult when the fog to be studied has been blown inland from the sea where little is known of the mean conditions of water temperature and air moisture, and less concerning their daily fluctuations.

Moreover in most places fog occurrence is not periodic, but is so irregular as to be apparently without any system.

The Bay of San Francisco furnishes a particularly interesting case of periodic sea fogs which are thus described by Prof. A. G. McAdie in the MONTHLY WEATHER REVIEW, July, 1900, p. 284.

> With almost clocklike regularity in the vicinity of the Golden Gate on summer afternoons the velocity of the wind rises to about 22 miles per hour and through the gate comes a solid wall of fog, averaging 1500 feet in height, and causing a fall in the temperature to about that of the sea, namely 55°;[1] 1500 feet above, the air is clear and 20° or 30° warmer.

The fog photographs accompanying the text in Bulletin 31 are remarkably beautiful. In the interesting Fog Studies which are devoted to the consideration of these San Francisco Bay fogs,[2] Professor McAdie concludes:

> It is more probable that condensation is the result of the sharp temperature contrasts at the boundaries of certain air currents having different temperatures, humidities, and velocities, and that the contours of the land play an important part in originating and directing these air currents. The summer afternoon fogs of the San Francisco Bay region are then probably due to mixture more than radiation or expansion.

The summer fogs of the east coast of Massachusetts have been studied by Clayton. He concludes that they are due to the flowing of a warm, damp, air current from the south over a very cold westward current off the water.

> Intermixture of these two currents goes on until they are churned to the bottom.[3]

Neither of the foregoing explanations of fog formation seems to suit the case of the summer fogs of Buzzards Bay. Here there are no hills or mountains as around San Francisco, and there is no crossing of air currents as observed by Clayton on the east coast of Massachusetts.

On fog days both the upper and lower winds blow from substantially the same direction, viz, southwesterly.

In order to study these fogs, the writer, during the summers of 1901 and 1902, made tri-daily observations of temperature, moisture, barometric pressure, wind direction, and velocity, and noted every case of fog formation, except when asleep at night. The station of observation is on Sconticut Neck, which extends southward into Buzzards Bay on the east side of New Bedford Harbor.

It early became apparent that there is a relation between the air pressure and the appearance of fog, and the completed records for the two seasons show that there was no instance of fog when the controlling conditions were anticyclonic. This, in part, explains why these fogs as a rule form only when the wind is southwesterly and not when equally cool ocean winds come in from southeast and south. As long as the winds come from southeast and south the conditions are at this season usually anticyclonic, and the air is too dry for fog. By the time the wind has veered to southwesterly the pressure and circulation have usually become either normal or characteristic of an approaching cyclone.

In summer there is usually a haze over the water which looks like an inland summer haze, but here it is evidently of aqueous origin, for it is found when the winds are from seaward. It is of variable tenuity, but in ordinary fair weather it is generally dense enough to make the bluffs of the Falmouth shore, 11 miles across the bay, invisible from this station. It is in fact thin fog, though we are not accustomed to call visible aqueous vapor in the air fog until it is dense enough to eclipse objects near at hand. In making entries of fog observations it is often difficult to decide whether this veil over the water should be called fog or haze; one grades into the other insensibly.

The descending dry air of a passing anticyclone always dissipates this haze, leaving the air beautifully transparent, and brings clearly to view single houses on the Falmouth shore. The contrast is very striking. At such times the sky is sometimes entirely overcast with high stratiform clouds, mostly strato-cumulus, apparently showing that the descending air is confined to the lower strata. This entirely clear condition of the air is always of short duration. The haze persistently returns, and is present much the larger part of the time. The psychrometer also shows that the normal condition on shore here during July, August, and September is one of high absolute humidity favorable to fog formation, occasionally and briefly interrupted by anticyclonic dry air, but ordinarily the amount of vapor falls a little too short, and the temperature holds a little too high to permit the intense condensation called fog. For the two seasons, during the periods of observation, the percentage of foggy days in the ordinary sense was 21.5. This normal condition of high humidity, however,

[1] Weather Bureau Bulletin No. 31, p. 32.

[2] Weather Review, August and November, 1900, and January, 1901.

[3] Weather Bureau Bulletin No. 31, p. 35.

is favorable for conserving any fog that may be translated hither.

It is customary to speak of saturation as a critical condition depending upon a vapor pressure which is constant for a given temperature and must be reached before condensation can occur, and which if exceeded is always followed by condensation.

Under this theory it is difficult to account for the presence of the watery haze that is usually found over the bay in summer, even with low relative humidities.

The persistent aqueous haze over the bay with winds from seaward, seems to indicate not only that the saturation temperature is different for different kinds of nuclei, but also that under ordinary conditions the variety of suitable nuclei is large enough to make condensation a gradual process rather than a catastrophe at a certain critical vapor pressure. This haze was observed with a southerly wind and with a relative humidity on shore as low as 52 per cent by sling psychrometer. The difference between the shore humidity and that over the bay can not be large, for where the observations were made the neck of land is only about one quarter of a mile wide, with $2\frac{1}{3}$ miles of water on one side and 11 miles on the other.

In general the transparency of the air increases and decreases inversely with the vapor pressure and the relative humidity, as shown by the psychrometer, but the changes of opacity do not follow with equal step either the dew-point or the relative humidity. In a few cases the divergence is notable. In the case cited the air was hazy, with a relative humidity of 52 per cent, and at another observation it was clear at 85 per cent. Whenever the air was clear, with high humidity, absolute or relative, the conditions were unusually anticyclonic or the temperature low. Occasionally the transparency increased with increasing relative humidity, and sometimes, though less frequently, with a rising dew-point.

Single cases of the occurrence of transient aqueous haze or denser fog, when the relative humidity by the psychrometer is less than 100 per cent, can be accounted for by mixture of saturated foggy air with air of lower relative humidity. If the mixture is nearly saturated the fog will evaporate slowly.

But it is unlikely that the persistent haze mentioned is caused in this way; for it would require a region to windward with nearly continuous fog, which has not been observed.

Generally fog is not a condition of complete saturation of the air, but a saturation of certain foci with drier interspaces. The sling psychrometer showed a relative humidity of 100 per cent only twice during the two seasons with 54 total cases of fog. The delicate adjustment of moisture and temperature conditions accompanying the formation and dissipation of fog, or the effect of dust or other nuclei for condensation are shown by the fact that fog is sometimes seen to thicken, dissipate, and even disappear, under stationary conditions of dew-point, temperature, and wind, when the temperature is read to half degrees and the dew-point computed from tables with half degree intervals.

The rate of increase of the vapor pressure after the passing of an anticyclone is extremely variable. The dew-point has been seen to rise 20° within twenty-four hours. At other times the absolute humidity might be a week in making the same increment. In order to readily see what changes of temperature and dew-point usually precede the appearance of fog, the temperature and dew-point observations were plotted and curves drawn. It at once became apparent that the antecedent conditions are a simultaneous rise in the dew-point and a fall of temperature.

Evaporation from the surface of the warm, shallow waters of the bay and sounds suggests itself as a possible source of the vapor increment, and the lower temperature of the ocean surface outside of the islands as the source of the cooling. But on reflection it is seen that an increase of vapor pressure due to local evaporation would not be so sudden as the rise of the dew-point curves just prior to the appearance of fog, and that it would take but a short time for an inshore wind to blow away the accumulated excess of vapor from these limited regions of warm water. Evaporation would not go on fast enough to supply sufficient vapor for a fog lasting for days with a continuous southwesterly wind. The further difficulty arises that this would not account for the intermittent character of the cooling which precedes the fogs, for the cool sea breeze comes in almost daily.

Accordingly the scene of inquiry must be shifted seaward. A comparison of the fog records of the Vineyard Sound Light-vessel (lying 16 miles to windward, south-southwest) on fog days; of the Gay Head Light-house ($16\frac{1}{2}$ miles to windward, south), and of the Block Island Southeast Light-house (42 miles to windward, southwest), with the shore observations, shows that these offshore stations, almost without exception, had fog on the days when it was observed on shore, and also on many other days when it did not appear on shore. Evidently then the fogs are formed some distance at sea and are brought ashore by the winds. This view is also confirmed by the sharp rise in the dew-point curves just prior to fog occurrence while the temperature curve is descending. As might be expected the curves show that in general (when free from the drying influence of high pressure areas and of winds from the interior) the vapor pressure rises with the temperature. But the sudden increase of absolute humidity with lower temperature indicates that the cool inflowing foggy air must at some time earlier have been warmer than the shore air which it displaces in order to have accumulated the extra moisture. To find water (and therefore the lower air) warmer than that of the shoal waters of the coast it is necessary to go many miles out to sea.

The North Atlantic Pilot Charts of the United States Hydrographic Office show that ocean fogs occur throughout the year over the shallow waters extending from the shore out to the 100-fathom curve all along the coast from Hatteras to New Foundland, and thence eastward in a narrow belt across the Atlantic. Off the coast of the Southern States the 100-fathom curve runs substantially parallel with the shore line about 85 miles distant. From Virginia the distance gradually widens to 105 miles south of Cape Cod and to 180 miles south of Newfoundland, where the curve turns sharply southeastward and off Cape Race is 300 miles from shore, being there the outer boundary of the Grand Banks.

The area of the fog belt and the frequency of occurrence vary with the season, but being greatest in June and least in February. To the westward of the sixty-sixth meridian, which runs near Cape Sable, Nova Scotia, the distribution of fog reported by vessels, as shown on the Pilot Charts, corresponds very closely with actual fog occurrence up to within 1° of the shore line, in the opinion of the Hydrographic Office.

The southern limit of summer fogs off the shore of Buzzards Bay is about 125 miles distant, the region of greatest frequency being about half that distance. To the south of the bay, outside of the first one-degree belt, these charts show for June a fog frequency exceeding that observed on shore; for July and August about the same frequency as on shore, and for September less than on shore. To the southwest of the bay, whence most of the shore fogs come with the prevailing winds, the frequency, beyond 1° from shore, is greater than the shore frequency for June, and less for the rest of summer. After June the line of maximum frequency evidently moves shoreward. Sufficient observations are wanting for the 60 miles next to the shore, but that the maximum does not reach the shore is made evident by the sudden rise in the dew-point just before every appearance of fog.

The more frequent occurrence of fog in the region south and southeast of the bay than in that to the southwest would naturally be expected to make the southeast and south winds more frequent carriers of fog to the shore than winds from the southwest. The reason why this is not the fact seems to be, in part, that the southeast and south winds here in summer are usually anticyclonic, and the downward component of motion partially dissipates the fog, and, in part, that to the southward and southeastward there are intervening islands, which tend to dry the incoming winds.

The June maximum, which is found generally along the Atlantic fog belt, does not occur in Buzzards Bay, partly because the summer monsoon has not yet become well enough developed to bring the fog in, and partly because the air over the waters near the shore and the land is yet sufficiently dry to evaporate some of the incoming fog.

Since the shore fogs of the bay are mainly blown in from the ocean fog belt, which skirts the coast of the United States and the Provinces, a study of the formation of the shore fog involves that of the main belt.

The Annals of the Deutsche Seewarte for 1897, Part IX, contain for each month of the year fog charts of the North Atlantic, west of 40° west, based upon the total number of cases of fog occurrence observed and reported by Dutch and German vessels within one-degree square for a period of twelve years from longitude 40° to 60° west (mid-ocean to Cape Breton Island), and for twenty-one years from 60° to 70° west (Cape Breton Island to Cape Cod).

The occurrence of fog in the eastern half of the Atlantic is not charted because it does not occur frequently enough to be deemed a substantial menace to navigation. This region is, however, covered by the fog charts of the United States Hydrographic Office for the months of July to December for the three years 1899 to 1901.

In the German charts there is entered in each one-degree square the whole number of observation hours and the percentage of the whole on which fog occurred. Lines of equal percentage of fog frequency are drawn through these squares to assist the eye in following the fog distribution.

It is the custom for steamships between the United States and Europe to follow in general a certain track or lane of moderate width on the outward voyage and another on the homeward voyage; consequently the weather observations are unequally distributed over different regions of the Atlantic and more cases of fog occurrence are likely to be observed within those limited belts which are traversed by the largest number of vessels. On this account care should be exercised in inferring the actual distribution of fog from the observed distribution.

Along these routes also the observed fog frequency is likely to be nearer the actual frequency by reason of the larger number of observations.

The entry of the whole number of observations in each square shows the distribution of the observations, and enables one, in a measure, to estimate the effect of unequal distribution of observations upon the lines of relative fog frequency.

The Monthly Fog Charts of the United States Hydrographic Office for the months January to June are based upon the German charts. For the remainder of the year they give the results of the observations of all vessels reporting to the Hydrographic Office for the three year period 1899-1901. In each one-degree square is entered the number of observed fog days in every hundred. There is nothing to indicate the total number of observations or their distribution.

The figures of fog frequency on the German and American charts relate to such long periods of time that the charted belt in the North Atlantic where fog has been observed extends unbroken entirely across the ocean from the United States to Great Britain. The lines of equal frequency show broadly that there is an axis of maximum actual fog occurrence lying along the coast of the United States and the Provinces inside the 100-fathom curve as far as the Grand Banks of Newfoundland, where it turns northward and eastward and crosses the Atlantic to Great Britain with a frequency diminishing rapidly after leaving the Grand Banks. The frequency also diminishes rapidly to the southward, so that on the southern edge of this belt the region of charted zero fog occurrence is within the district frequently traversed by vessels, and is not a long distance south of the axis of maximum frequency. It is the opinion of the United States Hydrographic Office that the southern limit of charted fog approximates pretty closely to the southern limits of actual fog occurrence. On the north the observations are much less numerous, and the distribution of fog in that direction is not so certain, but the frequency appears to decrease also toward the north, and there are reasons for expecting such a diminution.

The purpose of these charts is only to show to the mariner the probability of encountering fog. They give no indication of the actual distribution of fog at any instant or of the other attendant weather conditions which are needed in considering how the fog is formed.

The United States Weather Bureau collected and published monthly, in the WEATHER REVIEW, current observations of ocean fog west of 40° west, from 1886 to 1895, and for nearly the whole period monthly charts of the same were published. For more than two years of this period, viz, from November 1886 to December 1888, detailed analytical summaries of the conditions attending each case of fog formation, especially with reference to cyclones and anticyclones and the resulting winds and the presence of ice on the Grand Banks, were given monthly.

From the charts and summaries it is seen that the fog belt, which is shown as continuous on the Hydrographic Office and Seewarte charts, breaks up when charted monthly into a few separate areas which from time to time extend and contract their limits, but which tend to be persistent over certain definite regions, viz, over the Banks of Newfoundland, the Sable Island Banks, Georges and Nantucket shoals, and along the United States coast southward. These loci of maximum fog occurrence are all in the comparatively shoal waters inside the 100-fathom curve, and are divided from one another by arms of deeper water extending shoreward from the adjacent ocean deeps.

On comparing the various fog charts with the charts of North Atlantic surface isotherms by Krümmel, published in Agassiz's Three Cruises of the *Blake*, it is seen that the portion of the fog belt from the Grand Banks westward is over cold water which has close alongside to the southward the warm waters of the Gulf Stream and adjoining branch of the equatorial current. The temperature gradient is so steep that over and just south of the Grand Banks there is a fall of surface temperature in September of 30.6° F. in 320 miles and in March of 28.8° in 120 miles. A sharp temperature contrast exists all along the fog belt from Hatteras to Newfoundland. East of the Grand Banks the surface isotherms bend sharply to the north and then eastward in the latitude of Newfoundland, but with rapidly increasing intervals, showing a marked decrease in the surface temperature gradient. But it is significant that the axis of maximum fog frequency continues to follow the direction of the isotherms, just as it does west of Newfoundland. This is precisely what would be found if these fogs were caused by vapor blown transversely across the isotherms and cooled by [radiation to] the water.

The WEATHER REVIEW monthly summaries show that in nearly all the cases the occurrence of fog west of 40° west was attended by the easterly or southerly winds of cyclones and that the fog was denser than when the wind came from other quarters.

The observations of surface ocean temperatures by the United States Fish Commission, Coast Survey, and other occasional observers, notably the British steamship *Challenger*, show that there is a belt of cold water lying along the Altantic coast of the United States. This belt is flanked on the outside by the warm waters brought from the Tropics by the Gulf Stream and the adjacent Atlantic branch of the equatorial current. These observations also show that the surface waters of the Gulf Stream and of the outer portion of the cold coast water are streaked with alternate warm and cold longitudinal bands, with sharp temperature contrasts at their margins. These bands are continually changing their actual and relative positions.

Lieutenant Pillsbury, in his Memoir on the Gulf Stream,[4] says there is no perceptible current flowing southward along the United States coast inside of the Gulf Stream, though the Hydrographic Office charts show traces of one, and Alexander Agassiz found at Newport, R. I., marine animal life belonging to the arctic fauna, which he says is direct evidence that the cold arctic current finds its way round Cape Cod to the opening of Narragansett Bay.

But whether it be appropriate to call this the Labrador current or not, there is no dispute that it is cold water in sharp contrast with the temperature of the water lying just outside, and, so far as temperature goes, it is a practical continuation of the Labrador current.[5]

As far south as Hatteras the 100-fathom curve is substantially the dividing line at the surface between the Gulf Stream and the cold coast waters.

The slope of the continental shelf is very gentle out to the 100-fathom curve, where it suddenly becomes steep and descends to the 1000-fathom line within a few miles. Outside of the 100-fathom line the arctic current underruns the Gulf Stream current.

We have seen that the 100-fathom curve is also substantially the southern limit of the Atlantic fog which forms over the cold shallow waters lying just north of the curve. The editor of the WEATHER REVIEW concluded that the cooling over the arctic current of warm moist air brought from over the Gulf Stream by the easterly and southerly cyclonic winds usually attending fog occurrence is the efficient cause of the condensation of most of the fog. It was apparently assumed that the moisture and cooling were sufficient in amount to produce the effect, and the question of the method of cooling, whether direct or by mixture of air masses, was not distinctly raised.

According to Krümmels charts of surface isotherms of the North Atlantic the mean temperature in September of the ocean water in the latitude and longitude of Cape Cod is 67°, and 270 miles south the temperature is 80.6°.

There are at hand no data of relative humidity over the open ocean. The average relative humidity of all the West India Weather Bureau stations for 1900 was 79.4 per cent with a mean temperature of 78.5°. Judging from this it is not likely that the vapor at the point mentioned, 270 miles south of this coast, is more than 80 per cent saturated, and the humidity of the air at 67° near the shore is considerably smaller.

But assuming a relative humidity of 80 per cent for both bodies of air there is no mixing ratio which would produce condensation, as will readily be seen by projecting the saturation curve and plotting the temperatures and humidities of the two air constituents according to von Bezold's graphic method. In order to saturate air at 80.6° temperature and 80 per cent relative humidity by mixture, the other component would have to be as cold as 55° with a relative humidity of 100 per cent.

Obviously then these fogs are not produced by mixture.

But in traversing the cold water surfaces to the northward the warm moist air from the south must be cooled by conduction and by radiation. Direct cooling is much more efficient in causing fog than cooling by mixture. Air at 80.6° and relative humidity of 80 per cent would need to be cooled only to 73° to become saturated.

It seems likely that under the conditions named, a thin stratum of the warm air just above the surface of the water would, by contact with the colder water and by the gentle stirring of its own mass caused by friction with the water surface, become cooled sufficiently for condensation, in a journey considerably shorter than 270 miles.

These conditions of propinquity of warm, moist air and cold water surface with the necessary winds to carry the vapor over the cold surfaces are found in varying degree over the entire North Atlantic fog belt. In general wherever the highest humidities and sharpest temperature contrasts are found the frequency of fog is the largest.

There is no evidence that any such crossing of moist air currents from the south over cold lower currents from the east, as Clayton observed at Blue Hill, generally attends the formation of fog along the Atlantic fog belt; the Weather Bureau fog and weather records seem to indicate the contrary.

There is no question about the accuracy of the Blue Hill observations, and they are not at all in conflict with the foregoing theory of fog formation. An overflowing current from the south would not interfere with the bringing in of fog from the Georges or Sable Island fog banks by easterly winds, and it might intensify the condensation at the bounding surfaces, but it is not easy to see how there could be any "churning" throughout the lower layer while the warmer current is on top.

There remain many cases of fog (though a small percentage of the whole number) unaccounted for. In the vicinity of the Grand Banks for the period May, 1887–December, 1888 (when the WEATHER REVIEW gives the number of fog days for each month), the winds were in the south and east quadrants of lows on 91 per cent of the fog days. Of the remaining 9 per cent, 2 per cent of the fog days had winds from the colder regions; the other 7 per cent had variable winds, wind northeast, and wind direction not stated.

For the region west of the Grand Banks the data are not specific enough for a precise computation of the ratio of north and west winds to those from the south and east on fog days. It is evident, however, that the percentage of fog with north and west winds is considerably larger in this region (west of 60° west) than for the vicinity of the Grand Banks. It is, perhaps, as much as 10 per cent.

It is noticeable that this class of cases is larger during the summer months when the tropical surface waters are farthest north; and also that these cases increase relatively to the whole number of fog occurrences where the contrasts of temperature are likely to be sharpest, though only at exceptional times during the warm months.

Fogs with these northwesterly winds usually occurred immediately following the passage of lows to the eastward. It is not easy to conjecture exactly how the observed conditions conspired to produce this class of fogs. The editor of the WEATHER REVIEW attributed the condensation to "the contact between cold northerly winds to the west of lows and the warm, humid air from the Gulf Stream that had been collected in that region by the winds preceding storm centers."

The winds of a cyclone usually veer gradually, so that there is little opportunity for air from any special region within the influence of the storm to accumulate in any other region, and in general there is in a low no well-defined bounding surface separating bodies of air having marked contrasts in temperature and moisture. When a depression takes the V or trough shape the contrasts are sharp, and it is conceived that for a short time after the shift of wind to the west and north the conditions would be favorable to fog condensation, but they would be transient.

[4] Appendix 10, United States Coast and Geodetic Survey Annual Report, 1890.

[5] See Agassiz's Three Cruises of the *Blake*.

That the conditions attending fog formation during this shift of wind are exceptional and pronounced is evident from the fact that in nearly all cases of fog formation attending the passage of a cyclone the fog is dissipated upon the shift of wind to the west and north.

According to von Bezold:

The fog above warm, moist surfaces, under the influence of colder air, therefore, especially the fog over the sea in the cold season of the year or during the occurrence of cold winds, may be considered as originating by mixture.[7]

But for the authority of the eminent physicist, one would be inclined to question whether fog banks of considerable depth and permanency are formed over the ocean in this manner.

In air mixtures the cooler component dries the moister one while it cools it. The difference in temperature may be large enough to overcome the drying effect; but the cloud formed is likely to be transient, as seen in the momentary condensation of the breath on a frosty morning. Sufficiently large contrasts in temperature are usually wanting under ordinary weather conditions; and there is the difficulty of mixing two large, unconfined bodies of air of different temperatures and humidities to be overcome.

Notwithstanding some discontinuous motion at their meeting surfaces two contiguous air currents having different directions or velocities slip by each other with much ease and are little inclined to mix. Moreover in the reported cases of fog banks the existence of such counter currents is not usually noted.

In case of a cold wind blowing across the surface of warm water, there is apparently little or no condensation by mixture of air masses. The process, as observed at this station by the writer, seems to be somewhat as follows: The vapor evaporates at the warm water surface directly into the cold air current above, and is immediately condensed. By reason of its smaller specific gravity, due either to the vapor or to warmth from the water or both, the thin cloud of fog rises slowly, mixes with the drier air, and is swept to leeward, evaporating in whole or in part. Thus, the effect of whatever mixture occurs in such cases is to dissipate rather than to condense the fog.

Evidently the amount of vapor momentarily evaporated is too small to create much of a cloud unless it be allowed to accumulate, and this is prevented by the wind. The more moderate the breeze the more vapor will be taken up per unit volume by the overflowing air. But in any event the volume of moist air must be small in comparison with the drier air above, and it will, therefore, be quickly evaporated if the two become thoroughly mixed.

The details of the conditions attending the formation of the fogs with north and west winds are not sufficiently given in the WEATHER REVIEW summaries to permit confident conclusions to be drawn as to the precise operation of the causes which produce the fog cloud. The volume and persistence of these cold-wind fogs are not stated, except that they are not so dense as the fogs which form with south and east winds.

To hazard a conjecture, it is, perhaps, not impossible that this class of fogs is formed something as follows: The water over the shoals being for some reason abnormally warm, the customary condensation of fog does not take place while the winds are from a southerly direction. These warm winds raise the temperature of the water still higher, so that when the wind shifts to northwest it finds evaporation uncommonly rapid. If the winds from this quarter should happen to be exceptionally cold, all the conditions would favor condensation near the surface which might be sufficient in amount to resist for a time the drying which usually attends northwesterly winds.

[7] Translated by Abbe, page 285 of his Mechanics of the Earth's Atmosphere.

In the case of the San Francisco Bay fogs it is difficult to understand how mixture and condensation at the bounding surfaces of a moving body of air 1500 feet deep and several miles wide could be sufficient in amount to make so large a volume of fog, and to keep it replenished and undiminished in size, while it is being continually swept away at the velocity of 22 miles an hour.

The history of the North American fog belt suggests the possibility that an inquiry into the temperature conditions of the coast and offshore waters of California might throw light upon the fogs of San Francisco Bay.

There remain to be considered a few cases of fog of another class, viz, high barometer fogs. It was noted above that during the two summer seasons of the Buzzards Bay observations no case of fog was found with a high barometer, but the WEATHER REVIEW summaries show a few such cases on the offshore banks. They are all in colder months of the year, some with east and south winds, some with west to north winds, and some with variable winds. The details are mostly lacking.

The small number of fog occurrences with high pressure shows that under exceptional conditions the horizontal components of the winds may be so much more important than the vertical components that the air may be cooled by horizontal translation enough for condensation in spite of the drying effect of a moderate downward movement.

The main factors in the causation of the North Atlantic fog belt seem to have been settled by the investigations of the Weather Bureau above mentioned. They are summed up in Weather Bureau Bulletin A thus:

The fogs are apparently due to the precipitation of aqueous vapor contained in warm air from over the Gulf Stream, which is drawn over the cold surface of the arctic current and ice fields by southerly winds of the eastern quadrants of areas of low pressure.

This leaves unexplained some of the attending local phenomena, notably the division of the fog belt into patches of maximum frequency tending to be persistent over certain regions (the Grand Banks, Sable Island Bank, Georges and Nantucket shoals), but sometimes shifting their locations and usually undergoing continuous changes in size.

On the Grand Banks, by reason of the presence of the narrow Labrador current close to the shore and the floating ice, the sharpest surface temperature gradients of the Atlantic are found, and this abundantly accounts for the persistent formation of the fog in this region.

There is a similar though less strong tendency of fog maxima to persist over the Sable Island Bank and the Georges and Nantucket shoals; and it is not at once obvious what makes the waters of these shoals colder than the water in the straits or deeps of the ocean which extend shoreward between these banks, though this is doubtless the fact. Major Dunwoody says it is due to the "forcing to the surface of the cold, deep-flowing waters of the arctic current;" but he does not explain the process. Lieutenant Pillsbury thinks the low temperature over the shoals "is probably due to the cold water from the outside being forced on the shore by the advancing tidal impulse."[8] But why the warm surface water does not come in with the tide as well as the cold waters from the deeps is not explained, nor how the tidal wave is transformed into a current in waters "from 40 to 80 fathoms" deep. The course of the Labrador current along the coasts of the Provinces and eastern New England would seem to sufficiently account for the low temperature of the water over the continental shelf, the chief question being as to the cause of the higher surface temperatures frequently occurring in the deeps which divide the shelf into separate banks and shoals.

On a schematic chart of the Deutsche Seewarte, showing the currents in the Gulf of St. Lawrence and vicinity, the main

[8] Gulf Stream Investigations, p. 596.

current in Cabot Strait between New Foundland and Cape Breton Island is southward; but an eddy or countercurrent is shown running back northward along the western coast of New Foundland and then recurving into the main outward current from the Gulf. This eddy current would carry warm water northward, making a bight in the surface isotherms, and thus separating the Grand Banks from the Sable Island Banks by a tongue of higher temperature. Possibly there may be a circulation of water in the Bay of Maine whereby currents of warm water divide the Georges Shoals from the Sable Island Bank on the east and from the Nantucket Shoals on the west.

The deep narrow arms of the sea extending into the Bay of Maine and the Gulf of St. Lawrence from the south between these banks and shoals are suggestive of the possibility of such currents, and their effect would be to divide the waters of this region into thermal districts corresponding in general with the observed loci of fog maxima.

East and west the distribution of fog ought to follow pretty closely the variation of water temperatures, when the winds are southerly. But north and south the distribution will depend largely upon the winds which carry it along.

If the division of the fog belt into local maxima over the Nantucket and Georges Shoals and the Sable Island Bank is due to currents in the straits or narrow deeps between these shoals, the currents can not be continuous in time or constant in direction; for fog frequently extends across these deep straits making an unbroken belt; and in some months there is a maximum of fog occurrence directly over the large deep in the bays of Maine and Massachusetts, and also one over Cabot Strait deep. This would indicate a cessation or a reversal of the currents at times. The data at hand are not sufficient to show whether the shifting of fog from the shoals to the deeps and back again is systematic. In addition to the tendency of the fog belt to break up east and west into local areas which are not constant, except over the Grand Banks, there is a persistent tendency of the frequency to increase to the northward, the lines of equal percentage of frequency running east and west, with the line of maximum frequency skirting the coast of Maine and the Provinces close inshore. The Seewarte charts show an increase of frequency shoreward from 10 to 50 per cent in April, 10 to 60 per cent in May, and 10 to 70 per cent in June. In July the line of maximum frequency is somewhat offshore, decreasing both to the north and to the south. In every other month the percentage increases going north.

Undoubtedly the water is coldest where fog is most frequent; but the cause of the shifting about of the coldest water areas is not apparent.

In the opinion of Alexander Agassiz[9] the longitudinal cold bands at the surface of the Gulf Stream current "have no regularity, and only represent at any given moment the unceasing conflict going on between layers of water of different velocities and of different temperatures." Here the arctic current directly underruns the warm water from the Tropics. How far inshore the conflict extends can not be stated; but observations of ocean surface temperatures in the fog belt show considerable changes from day to day, and differences of several degrees on the same day between stations near each other.

Most fog banks are shallow, and the winds which contribute to their formation need to be substantially horizontal for considerable distances. The frequent lack of such horizontal air movement due to vertical components of motion (which are usually unnoticed), and the want of uniformity in the temperature and moisture relations of the offshore waters explain the apparent capriciousness of the Buzzards Bay summer fogs, which so impress the casual observer.

[9] Three Cruises of the *Blake*, p. 254.

Acknowledgments are due to the United States Commission of Fish and Fisheries, the United States Coast and Geodetic Survey, the United States Hydrographic Office, the United States Weather Bureau, and Mr. F. Lawrence Briggs, mate of the Vineyard Sound lightship, for data and references to sources of information.

A PHOTOGRAPH OF LIGHTNING AT HAVANA, CUBA.

By W. C. DEVEREAUX, Assistant Observer Weather Bureau, dated October 19, 1903.

I have the honor to forward a photograph of lightning taken in this city September 16, 1903, at 10:28 p. m. (Havana time), by Señor Jose Gomez, a professional photographer of this city. Señor Gomez states that the shutters of his camera had been open about five seconds when a very vivid flash of lightning compelled him to shut his eyes, and at the same time pressed the bulb which closed the shutters. He thinks that the two prominent streaks of lightning, shown in the picture, occurred either exactly together or within a fraction of a second of each other.

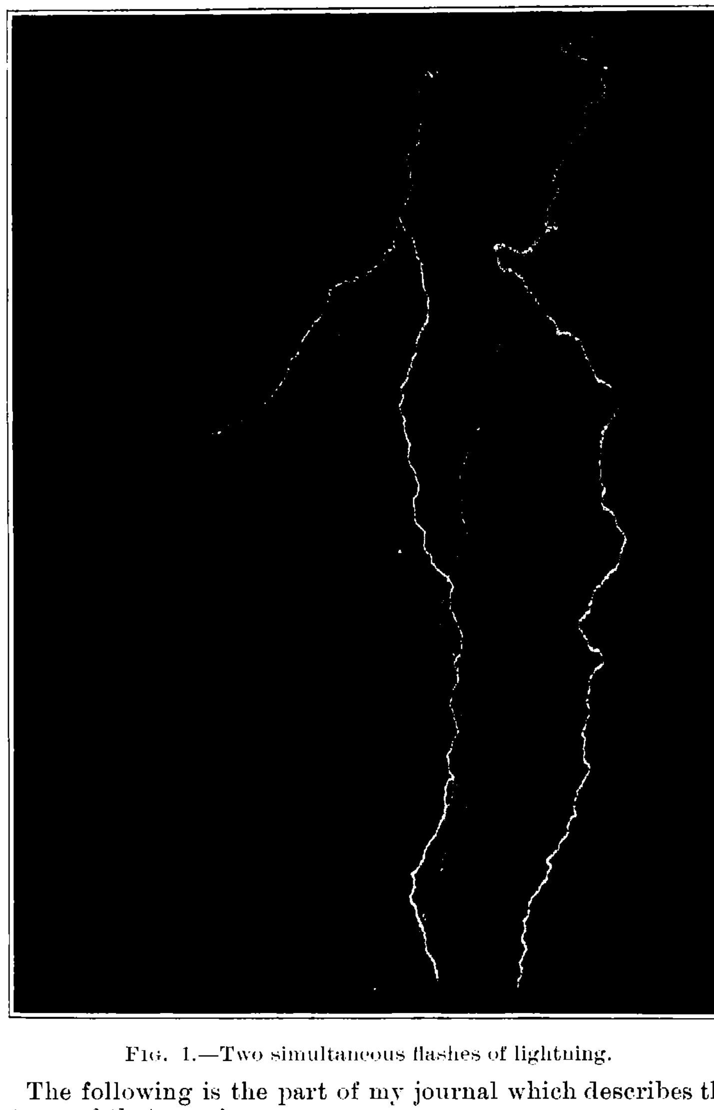

FIG. 1.—Two simultaneous flashes of lightning.

The following is the part of my journal which describes the storm of that evening:

Two very severe thunderstorms occurred late in the evening and at the same time. Thunder was first heard to the east at 9:35 p. m.; the center of this storm seemed to pass slightly to the northeast of the station, moving northwest. The first thunder of the second storm was heard to the southwest at 9:50 p. m.; the center of this storm seemed to pass over the western part of the city, moving north. The thunder from both storms was very loud from 10:30 p. m. to 10:50 p. m.; a light